

**Color Theory And Applications For The Graphic Arts**

**An Honors Thesis (HONRS 499)**

**by**

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**Muncie, Indiana**

**December 1992**

**Expected Graduation Date**

**May 8, 1993**

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## **Purpose of Thesis**

The purpose of this thesis is to provide a comprehensive discussion of color theory as it applies to the graphic arts. The discussion provides an explanation of how color is perceived and reproduced. Color is defined and the factors that distinguish one color from another are discussed. The thesis explains color reproduction processes and provides examples of equipment that is utilized for color reproduction in the printing industry.

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## **Color Theory And Applications For The Graphic Arts**

### **Introduction**

Color is fascinating. It is present naturally all around us. Imagine how dreary life would be without color. Many practical uses of color have been developed and improved upon over the years. Color is used more and more in many industries. As technology advances, color is used much more effectively. The printing industry is improving and refining its use of color at an excitingly fast rate.

Printing accounts for a large amount of the color that we see every day. Color is printed in books, magazines, and newspapers. It is found on signs, billboards, and posters. Color is printed on packages, beverage containers, appliances, and clothing. Almost every item that is manufactured involves some form of printing, usually color printing.

In a field so heavily involved with producing color, improved quality and consistency are ever present goals. Ink companies are striving for purer colors of inks. Printers are reproducing color photographs at very high levels of quality. Newspapers are using more color, including reproduced color photographs.

The following topics discuss and explain how color is used in the graphic arts. The principles of light and color are described. Photographic continuous tone color reproduction is one means of regenerating color that is discussed. Color separation techniques, both photographic and electronic, are also explained.

It is important for anyone who is to be involved with color reproduction to have a good understanding of color theory. Without this knowledge, quality color work can hardly be considered an achievable goal. This thesis presents a comprehensive view of color theory for the graphic arts. Once someone understands the

theory behind color reproduction, quality and consistency are easier to achieve.

## Light

Before someone can gain an understanding of color, they must first understand light. All of the colors that can be perceived come from light and all light has color. We perceive an object to be a certain color because of the color of light that is passed through the object or is reflected off the surface of the object (Mason et al, 12).

Light can be defined simply as energy (Dennis, 133), but to be more specific, it is a form of electromagnetic radiation. All electromagnetic radiation travels in waves (Adams, Faux, and Rieber, 135). There are many types of electromagnetic radiation including X rays, television waves, radio waves, gamma rays, and electricity, as well as light waves. What distinguishes one type from another is its wavelength. In his book Color, Harald Küppers defines the wavelength as “the distance from one wave crest to the next” (40).

The length of the waves determine the properties of each type of radiation. Light waves are usually referred to in units called nanometers (nm). A nanometer is equal to one billionth ( $10^{-9}$ ) of a meter (Hunt, 4). Light waves that are visible to humans are between 380nm and 720nm (Küppers, 40). This range of light waves is referred to as the visual spectrum.

The wavelength of the light determines its visible color. Each wavelength of light has its own color, or hue (Hirsch, 2). Violet hues have the shortest wavelengths, 450nm and less. Blue hues are next, ranging from 450nm to 480nm. These are followed by: blue-green 480nm to 510nm; green 510nm-550nm; yellow-green 550nm-570nm; yellow 570nm-590nm; and orange 590nm-630nm. Red hues have the

longest wavelengths, 630nm and greater (Hunt, 4).

Humans are able to perceive light because the wavelengths are the proper length to stimulate the optic nerve (Adams, Faux, and Rieber, 136).

Light enters the eye through the cornea and passes through the iris. The iris controls the amount of light that passes through it. The light is now focused by the lens onto the retina, a thin membrane at the back of the eye (Hirsch, 4).

The retina is made up of light sensitive cells called rods and cones. When light hits the rods and cones, they translate the image into nerve impulses that travel through the optic nerve to the nerve cells in the back of the brain. This information is then analyzed and interpreted by the brain. It is this combination of sensory response of the eye and interpretive response of the brain that allows us to see light. The brain is able to distinguish between the different wavelengths of the spectrum, which allows us to perceive colors (Hirsch, 4-5).

The rods record brightness differences. The cones are more complex. There are three different types of cones, each sensitive to a different area of the spectrum. The three colors of light that the types of cones are most sensitive to are bluish (shorter wavelengths), greenish (intermediate wavelengths), and redish (longer wavelengths). As a color stimulus reaches the eye, its spectral composition stimulates each type of cone differently. Each type sends a different value to the brain. The brain then interprets the combination of these values as a particular color (Küppers, 22-24).

## **Color**

Color would be of no value if the different colors of light could not be distinguished from one another. Colors can be distinguished from one another by identify

ing each color's *hue*, *saturation*, and *brightness*. When colors are identified by these attributes, it must be assumed that white, black, and gray are to be considered colors. It must also be assumed that a change in any one of these three attributes constitutes a change in color (Luckiesh, 70).

Hue refers to the family of colors that the color belongs to. For example, green, red, and yellow are color families, or hues (Hunt, 69). Sky blue is a color of the blue hue. Most hues are represented by spectral colors. These hues are referred to as *dominant hues* (Luckiesh, 70). A dominant hue is also referred to as a *dominant wavelength* because a spectral wavelength is the dominant color for the hue (Overheim and Wagner, 74). The exceptions to these hues are composite colors, or the purples. The composite colors are combinations of red and violet light. No spectral colors represent their hues. To determine the dominant wavelength of a composite color, find the dominant hue of its complementary color (Luckiesh, 70). This hue is then referred to as the *complementary dominant wavelength* (Overheim and Wagner, 75).

The second attribute is saturation. This is sometimes referred to as *purity*. Saturation is a measurement of the relative amount of white light in a particular color (Luckiesh, 70). White, gray, and black have zero percent (0%) saturation. These colors are called *unsaturated*. Spectral colors have no white light in them. All dominant wavelengths are one hundred percent (100%) saturated (Hunt, 69). All of the other colors in the hue range between these two values (0%-100%) depending upon the amount of white light that they contain (Luckiesh, 70).

The last attribute that distinguishes one color from another is brightness. In his book The Reproduction of Colour, Dr. R. W. G. Hunt defines brightness as "the extent to which an area appears to exhibit light" (69). Brightness is the amount of white light that is reflected or transmitted from the color. Environment can have a

drastic effect on brightness. An object viewed in bright sunlight will appear brighter than an object viewed under a shady tree. For instance, if you were to look at a gray sheet of paper under each of these conditions, it would appear brighter under the sunlight. However, the sheet would still appear to be gray, not black. The reason for this is because the paper is judged relative to the brightness of objects around it. This concept of relative brightness is referred to by the term *lightness* (Hunt, 70).

### **The Additive Principle**

The three colors of light (redish, greenish, and blueish) that the cones of the retina are sensitive to are also called the additive primary colors. These colors are the basis for what is known as the additive principle of color. These colors, each occupying one third of the visual spectrum, are a combination of the wavelengths in each third (Adams, Faux, and Rieber, 242). Therefore, these three colors are able to cover the entire range of the visual spectrum.

Transmission refers to light passing through an object. Many translucent materials are colored. When these materials are used as filters with white light sources, they produce colored illuminants (Overheim and Wagner, 39). For example, if we have a piece of red glass and we shine a white light through this glass, the light that passes through will be red. This is because the red glass transmits the red light. What we are unable to see is that the glass is filtering the green and blue out of the white light (De Grandis, 53). The same principle is true for green and blue filters as well.

The additive principle is based on the fact that when all three additive primary colors of light are added in equal amounts, they produce white light (Hirsch, 9). By combining the additive primary colors in various unequal amounts, it is



possible to produce every other color of light in the spectrum (Adams, Faux, and Rieber, 242). The name 'additive' is used to describe this principle because the primary colors of light are added to each other to produce the other colors (Dennis, 262).

Adding any two of the primary colors together in equal intensities produces a special color. Red and green light produce yellow light. Blue and red light make magenta light when they are added together. Likewise, blue and green make cyan light. These three colors are called the complementary colors of the additive primary colors. Each complementary color "complements" the color that was not added to produce the complementary color. In other words, yellow complements blue because the yellow is made up of green and red light. Magenta complements green. Red and cyan are complements because red is absent from the cyan. When complementary colors are combined, say magenta and green, the result is white light. This is because all of the primary colors are present. In this case, green was added to magenta, which is made up of red and blue light (Overheim and Wagner, 42).

### **The Subtractive Principle**

The three complementary colors of the additive principle are the basis for a second color principle, the subtractive principle. Cyan, magenta, and yellow are called the subtractive primary colors (Dennis, 262). In theory, the subtractive colors also can be combined in different amounts to produce any color of the visual spectrum (Adams, Faux, and Rieber, 244).

Objects that do not transmit light use the subtractive principle to produce color. Reflectance refers to the amount of light that an object reflects off of its surface. If an opaque object appears white, then it is reflecting equal amounts of each

color of light. If an opaque object appears to be a certain color, then it is only reflecting the color that the object appears to be. The rest of the light that doesn't make up the color being reflected is absorbed into the object. For example, a tomato appears to be red because it reflects the wavelengths of light that make up that color of red and it absorbs all of the other wavelengths of light (Mason et al, 12).

Absorption demonstrates why this is called the subtractive principle. In the additive principle, different wavelengths of light are added together to produce different colors. In the subtractive process, certain wavelengths are absorbed, or subtracted from the light source, by a given object to produce that object's observed color. (Mason et al, 12-13).

When the additive primaries are added together in equal amounts they produce white light. When the subtractive primaries (cyan, magenta, and yellow) are added together equally they produce an absence of light, or black. In essence, they have subtracted all of the wavelengths of light (Dennis, 262-264).

The additive and subtractive primaries are further connected. If any two subtractive primaries are added together in equal amounts, they will produce an additive primary color. This additive primary color then complements the third subtractive primary color. For example, if cyan and magenta are combined in equal amounts, they will produce blue. If yellow is combined with the blue, it will produce black. Therefore, blue is the subtractive complementary color of yellow. Red complements cyan and green complements magenta as well (Dennis, 262-264).

Objects that are opaque only reflect and absorb light. One hundred percent of the amount of light that hits an opaque object is absorbed and reflected. Objects that are translucent reflect, absorb, and transmit light. The amount of light that is either transmitted, reflected, or absorbed also totals 100% of the light source (Overheim and Wagner, 36). A colored filter is a good example of this. A yellow filter

is reflecting yellow wavelengths of light. This is known because the filter itself appears to be yellow. If a white light is passed through the filter, it transmits yellow light. A white object behind this filter would appear yellow because yellow is the only color of light that is hitting the object. We also know that the other wavelengths of light are being absorbed by the filter because the filter appears to be yellow. All of the light from the source is accounted for (Hirsch, 3).

### **Color Photography**

The most practical application of color theory for the graphic arts is the ability to capture and reproduce light. This is the basis for all aspects of color in this field. Photography is a process of capturing light. One way that this is accomplished is through the use of photographic films.

All photographic films record images with a light sensitive material called an *emulsion*. Generally emulsions are composed of silver halide crystals suspended in a gelatin compound (Adams, Faux, and Rieber, 139). The silver halide crystals are made up of silver particles combined with bromine, chlorine, or iodine. When light strikes the silver halides, the silver particles move together forming clusters. When the film is processed, the areas not exposed to light are washed away by a developer leaving only the clusters of silver. These clusters are what makes the image visible (Dennis, 181). It is important to note that since these clusters are formed by light striking the silver particles and the unexposed areas are washed away, a negative image is formed. This image must be reversed before the original scene is correctly depicted.

There are basically three types of emulsions based on their sensitivity to colored light. The first type of emulsion is blue-sensitive. This type of emulsion is

sensitive to the blue end of the spectrum and records very little from the green and red areas of the spectrum. Orthochromatic film is sensitive to blue and green light, but not sensitive to red light. The third kind of emulsion is panchromatic. This type of emulsion is sensitive to all visible colors of light (Adams, Faux, and Rieber, 137). Black and white photographic films are panchromatic because they are used to make a black and white continuous tone representation of all of the visual colors in a particular scene.

Recording color continuous tone representations on film is much more complex. Color negative film is made up of three blue-sensitive emulsions called an *integral tripack*. The first layer of emulsion records the blue light of the image. This layer is called the blue-sensitive layer because it is only sensitive to the blue light. The other two emulsions are also only sensitive to blue light. When the film is manufactured, sensitizing dyes are added to these layers to extend their sensitivity to green and red light. This makes it possible to record the entire range of the visual spectrum (Hunt, 205).

A yellow filter layer is located immediately below the first layer of emulsion. This prevents any blue light from reaching the other layers of emulsion. This is important because although the other layers have been sensitized to red and green light, they are still sensitive to blue light as well. The green-sensitive layer, located under the yellow filter, records the green light. The red-sensitive layer is the final layer. It records the red light (Hunt, 205).

These three layers are basically black and white emulsions each sensitive to one third of the spectrum. If white light hits an area of the film, the blue layer will record the blue light and allow the rest of the light to pass. Each layer will record its own range of light. It is the combination of these layers that allow all of the visual colors to be reproduced. For example, if a yellow light exposes an area of the film,

the blue layer will have no light to record, but the other layers will record green and red light respectively. This will represent yellow (Mason et al, 16).

Each emulsion has dye couplers in it. Each layer's dye couplers correspond with the complementary color of the color that it is sensitive to. In other words, the blue-sensitive layer contains yellow dye couplers, the green-sensitive layer contains magenta dye couplers, and the red-sensitive layer contains cyan dye couplers. The couplers are each capable of forming their corresponding dye color. The process of forming these dyes is known as *dye coupling* (Hunt, 206-207).

When the film is processed, the exposed areas of the emulsions are converted from silver halides to clusters of silver. An oxidized developer reacts with the couplers to produce the dyes. The dyes are deposited around each grain of silver. The unexposed silver halides are removed by a fixer. The exposed silver is also removed in a bleaching process. Sometimes these processes are done at the same time with a chemical blix; bleach and fixer combined. This process leaves only the dyes in place. These dyes are a negative representation of the colors that originally exposed these areas (Hunt, 207).

Another process produces color transparencies. This process is called a reversal process because the negative image is reversed on the film during processing to produce a positive image. The positive film is exposed the same as color negative film. It has the same light sensitive layers. The processing demonstrates the difference between color negative and transparency films (Mason et al, 16).

After the negative image of a transparency is developed, the remaining unexposed silver halides are then exposed by chemicals or with light. These silver halides are converted to metallic silver with a second developer that activates the dye couplers. The dyes are coupled to the silver clusters that are in the areas that weren't originally exposed to light. Therefore, the negative image has been reversed

to produce a positive representation of the original image (Mason et al, 16).

To illustrate this reversal, assume that blue light strikes a given area of transparency film. The blue light will expose the silver halides in the blue-sensitive layer and will leave the green and red layers unexposed. The film is developed the first time, changing the silver halides in the blue-sensitive layer to metallic silver. This developer does not activate the dye couplers. The remaining silver halides in the green-sensitive and red sensitive layers are now exposed. The second development now activates the couplers in the red and green layers, causing the green layer to be dyed magenta and the red layer to be dyed cyan. All of the silver is now removed leaving only the dyes. After processing, this area of the film will be seen as a combination of magenta and cyan (or blue) when white light is passed through it. Therefore, it is a positive representation of the blue light (Mason et al, 16).

A color negative of this same blue light would appear to be yellow. To produce a positive image from a color negative, another light sensitive material must be exposed and processed. The most common material used to produce a positive image from a color negative is color print paper. Color film and color print paper are similar in structure. Both have integral tripack emulsions with the same colors of dye couplers. They do differ in the fact that films usually have transparent base materials and print paper usually has an opaque white material for its base. Print papers use reflected and absorbed light to produce the perceived colors. Also the blue sensitive layer of most print papers is the third layer instead of the first layer as in films. This produces more accurate color balance from reflected light (Dennis, 283).

Print papers are also made for producing prints from transparencies. These papers are called reversal color papers. This process is referred to as the reversal-reversal process or the positive-positive system (Hunt, 220).

To produce a color print, a light source and a room of complete darkness are

needed. Since the print paper is sensitive to all wavelengths of light, it must be handled in complete darkness until it has been processed. The light source is used to project the image of the negative onto the print paper. The most practical way to project this image is with a tool called an enlarger. An enlarger contains a light source that can illuminate the film evenly. It can project images from different distances which allows for magnification of the image. Enlargers contain a lens so that these magnifications can be focused onto the print paper (Dennis, 222).

The most common type of enlarger to use for color prints is a diffusion enlarger. In this type of enlarger, light is mixed in a diffusing chamber. This causes the light to be traveling in many different directions when it reaches the film. The mixed light is called diffused light (Hirsch, 85).

Producing color prints usually requires that impurities and deficiencies in the enlarger's light source are removed before they reach the print paper. This is accomplished through the use of color correction filters.

Color negative films especially need to have the light filtered because they generally have an orange tint referred to as an orange mask. The orange mask allows for more accurate colors to be recorded on the negative by correcting for deficiencies in the emulsion layers. This orange color must be compensated for when prints are made. This compensation is called color balancing. Color balancing is also used to correct prints that show a color cast that is present due to incorrectly filtered light from the enlarger.

### **Photographic Color Printing**

One way to filter this light is through a system called tricolor or additive printing. A set of three filters are used in the tricolor method. These filters are the

colors of the additive primaries (red, green, and blue). During exposure, a filter is placed between the lens of the enlarger and the print paper. A separate exposure is made for each filter. Only one light sensitive layer of the print paper is exposed each time. Thus, each exposure "adds" one third of the light for the print (Tomlinson, 1).

In additive printing, proper color balance is obtained by adjusting the times of each exposure (Tomlinson, 1). For example, if the finished print appears to be too yellow, a new print is produced with a shorter exposure for the blue filter. Likewise, if the print has a blue cast, both the green and red exposures need to be decreased. This is because too much red and green light, the colors that make up yellow, have been added to the print.

Color prints can also be made using the subtractive method. In fact, this is the most common way that prints are produced today. In this method, filters that are the colors of the subtractive primaries are used to subtract light from the light source to produce the mixture of light that is necessary to expose a correct color print (Dennis, 286).

One way subtractive printing differs from additive printing is by the way the filters are utilized. There are only three filters used in additive printing. With subtractive printing, it is important to remember that the filters vary in density values. Many filters or filter density values are used for each subtractive primary (Dennis, 283-286). Also, only one exposure is made using the subtractive method as opposed to the three exposures additively. This is because the filters are used together to subtract some of the light from the light source. Usually only two of the three subtractive primaries are used to filter the white light at a time. This is because if all three were used, a shade of gray light would be produced (Dennis, 286).

The best system to use for subtractive printing is a dichroic system. This is a self-contained filtering system with a color-corrected high intensity light source.



The filtration can be adjusted simply by changing the units of density of any of the filters (Hirsch, 86).

If a dichroic system is unavailable, a regular enlarger can be converted for color printing with the aid of color print filters (Hirsch, 86). The filters are used manually to produce basically the same effect as a dichroic system. However, dichros are much more accurate. These filters are purchased as a set. A set usually contains 20 to 25 filters of various densities of cyan, magenta, and yellow (Dennis, 286).

An ultraviolet filter should always be used to remove the UV light from the light source. This prevents the UV light rays from upsetting the color balance (Dennis, 286). A dichro enlarging head already contains a UV filter so no extra ultraviolet filtration is necessary (Hirsch, 86).

To balance or correct the color in a print, the density values of the filters are added or subtracted (Dennis, 286). Once the proper density and brightness of the print has been determined, improper color balance can generally be placed in one of six categories. The unbalanced print will have a color cast (too much of one color) close to yellow, cyan, magenta, red, blue, or green. To correct this, more of that particular color of light must be filtered out, or subtracted (Hirsch, 96-97).

If a print from a film positive is too yellow, magenta, or cyan, then the units of that color are subtracted from the filter pack. Remember that one of the colors should remain at zero units to avoid gray light. If this is the color of the cast, simply add equal units of light to the other two colors. This allows the color of the cast to remain at zero (Hirsch, 109).

If a print from a film positive is too red, green, or blue, the units of that color's complementary color are added to the filter pack. For example, if the print is too blue, yellow units of filtration are added to the filter pack. In the cases where

the complementary color is also the zero units color, equal units of the other two colors are subtracted (Hirsch, 109).

All of this is reversed when making a print from a color negative. This is because it is the complementary color that produces any given color on the print paper. It was the same color when printing from a film positive.

So if a print from a negative is too magenta, cyan, or yellow, units of that particular color are added to the filtration. For example, more yellow filtration will produce less yellow in the print, and vice versa. In the case of the zero units color, equal units of the other two colors are subtracted (Hirsch, 96-97).

A print from a negative with a green, blue or red cast can be corrected by subtracting filtration units of the cast's color complement. If the print is too red, cyan units are subtracted from the filtration. If cyan happened to be the zero units color, then magenta and yellow could be added equally to the filter pack instead of subtracting cyan; therefore, allowing the cyan to remain at zero units (Hirsch, 96-97).

### **Graphic Arts Photography**

To understand how color is reproduced through printing processes, one must first have a general knowledge of how graphic arts photography works and its purpose. Understanding these principles will make comprehension of the other processes easier by providing insight into how the processes work and why they are necessary.

A special camera is used in graphic arts photography called a process camera. The process camera is usually significantly larger than other types of cameras. This is so that images large enough for the printing press can be photographed. It also

allows for reductions and enlargements of the original copy to be made on the camera (Adams, Faux, and Rieber, 140-145).

To photograph an image, the copy is placed in a glass-covered frame called a copyboard. Film is placed on a filmboard and is held in place by a vacuum. Enlargements and reductions are made by adjusting the distance between the copyboard and the lens, and also between the lens and the filmboard. If both are not adjusted properly, the image will not be in focus. The copy is illuminated by an artificial light source. The light passes through the lens and is focused onto the film. The exposed film is then processed to produce an image (Adams, Faux, and Rieber, 143-146).

Line photography involves copy of two tones. Although other colors can be photographed using filters, black and white copy is ideal. The black will absorb the most light and the white will reflect the most light; therefore, producing the sharpest image. Since only one tone needs to be recorded, a panchromatic film is unnecessary. An orthochromatic film is used for line photography. Ortho film can be handled under a red safelight because it is not sensitive to red light. This is easier to use than pan film that must be handled in complete darkness to keep from exposing it (Adams, Faux, and Rieber, 135-138).

In line photography, a solid image on the copy becomes a clear image on the film, when the film is processed. The white areas of the copy will become black and will not allow light to pass through the film. When this film is placed over a printing plate, the clear areas of the film will allow light from an exposure unit to expose the plate and the black areas will not. The image on the plate will be the same as the copy (Adams, Faux, and Rieber, 153).

This printing plate can then be used to print a black image on white paper or it can be used to produce what is known as fake color. Fake color is any single color reproduction printed on a colored sheet of paper. Colored ink on white paper, black

ink on colored paper, and colored ink on colored paper are all combinations of fake color. If more than one color of ink is used it is no longer fake color, but is referred to as flat or spot color (Adams, Faux, and Rieber, 65).

Line photography is only able to capture two tones: black and white. To capture shades of gray, a process called halftone photography is used. This process converts shades of gray into line negatives, but creates an optical illusion of continuous tones (Adams, Faux, and Rieber, 181). It is because of this process that printing presses are able to reproduce photographs. Printing presses can only lay down one shade of ink at a time per printing unit. This optical illusion allows for the ink to appear to be various shades.

The illusion is actually many small dots of various sizes. When a halftone image is printed, areas that contain large dots will appear to be darker than areas that contain small dots. The dots are referred to in the printed form as opposed to the negative form. The dot will be called a "negative dot" when referred to in the latter state. The dots are distinguished by their size which is stated in percentages. A 100% dot is a totally black area and a 0% dot is a totally white area. A 50% dot would be half white and half black (Adams, Faux, and Rieber, 184-185).

The dots are created on the negative by using a screen. The halftone screen is made up of lines that cross each other at 90° angles. The number of lines in one inch makes up the screen's ruling. More lines per inch produce better detail because more dots per inch are created (Adams, Faux, and Rieber, 181).

The screen is placed over the film before it is exposed. The light reflected off of the continuous tone copy is passed through the screen. Each dot is a separate exposure based on the amount of light that passes between the lines on the screen (Adams, Faux, and Rieber, 181).

A duotone is a printed representation of a continuous tone image that is

printed twice. It is basically two halftones of the same image that are printed one over the other. The halftones are referred to as light and dark printers. The light printer captures the highlight detail and the dark printer captures the shadow detail. The dark printer is exposed longer than the light printer, allowing for the different representation of detail (Adams, Faux, and Rieber, 216-222).

Duotones can be printed in the same color, which increases the density range on the printed image. Usually when this technique is used they are printed in different colors. A black or dark color is used for the dark printer and a lighter color is used for the light printer (Adams, Faux, and Rieber, 216).

When any two screened images are placed over one another, a moiré pattern occurs. This distorts the image. It is minimized if the screens are at 30° angles from one another. This is the optimal angle to avoid this problem (Adams, Faux, and Rieber, 217).

### **Color Separation Techniques**

To print a continuous tone color image, the colors of the original copy must first be separated. A printing unit on a press can only print one color at a time. Therefore, the subtractive principle is used to reproduce color images. In theory, all colors can be produced using cyan, magenta, and yellow inks. However, due to impurities and limitations in the inks, black is also printed so that the colors can be reproduced more accurately (Hunt, 538). Black adds to the density of the printed colors (Adams, Faux, and Rieber, 244).

The inks that are used are called process inks. These inks are translucent (Adams, Faux, and Rieber, 244). This quality allows the inks to act as filters on the paper by allowing their own color of light to pass through but absorbing the other

colors. When light is reflected off of the substrate, the inks subtract colors from the light. When two of the subtractive primaries of ink are overprinted, they produce the complementary color of the third ink.

The colors are separated into four negatives before they are printed. Just as with duotones, the separation negatives for each color are referred to as printers (Adams, Faux, and Rieber, 245). Each separation negative is a halftone representation of the original copy. The separation negatives are photographed one at a time using additive filters. The red filter will only allow red light to pass, producing the cyan negative. The green filter passes only green light, producing the magenta printer. The yellow negative is produced by the blue filter because it will only pass blue light. The black printer is usually made through a yellow filter (Jaffe et al, 13-14).

Since the printers are halftone representations of the original copy, they must be screened when they are exposed. To avoid moiré patterns when the four screened images are printed over one another, the printers are screened at different angles that allow for maximum clarity. Black is usually printed at a 45° angle. Cyan and magenta are printed at 30° intervals from the black, one at a 75° angle and one at a 105° angle. Yellow is printed at a 90° angle. This is 15° from the magenta and cyan inks. The yellow dots are the least noticeable, so yellow is chosen to be the color that is only 15° from the other colors (Hunt, 534).

Orthochromatic film can not be used to make the separation negatives because it is not sensitive to red light. For color separations, panchromatic film is used. Since it is sensitive to all the wavelengths of light, it must be handled in complete darkness until after it has been processed (Adams, Faux, and Rieber, 137-138).

Throughout the color separation process it is important to keep all of the

separated parts of the image in perfect register. If this is not done, the separation will not work. The best manual registration method to use for color work is a punch register system. In this system, a device is used to punch all of the materials that need to be registered. A set of registration pins that match the punched holes are used to insure that each punched item lines up with all of the others (Jaffe et al, 119-121).

A total system approach should be used for color work. The first step should be to punch all of the film at the same time. This insures that they all will be in register. The register pins should be mounted to the film board to register the films for each exposure. The pins and the copy should not be moved until all of the separations are made. In stripping, the masking sheets should also be punched to maintain registration. A separate sets of pins should be used to register the masking sheets. The plates should also be punched and registered in the plate exposure unit. The registration pins can also be used on the printing press to maintain registration from color to color (Adams, Faux, and Rieber, 297-298).

### **Masking**

In theory, the separations alone should reproduce accurate color on a printing press. However, many other things factor into the color reproduction which disturb the color balance. These factors must be taken into account. Masking is a photographic or electronic technique used for color correction. Proper masking can compensate for these problems (Jaffe et al, 75).

A photographic color mask is made by exposing the original image to a continuous tone pan masking film through a special filter. The mask is registered over the separation film before the exposure is made. The masking step is done electroni

cally with electronic color scanning. Using a computer, the final digital separation images are adjusted before they are outputted (Adams, Faux, and Rieber, 247).

Masking can serve several functions. One function is to compensate for deficiencies of the process inks. It is impossible to manufacture the process inks free from impurities. For example, magenta ink contains a small amount of green pigments, although it should only contain blue and red pigments. Masking reduces selected areas of the separation negatives to compensate for these deficiencies (Adams, Faux, and Rieber, 247).

Masking also serves to reduce the density range and preserve the highlight detail of the copy. Copy that has a greater density range than can be printed by a printing press can be compressed using masks. This copy could include transparencies, dye transfer prints, and oil paintings. The highlight detail that is usually reduced in halftone procedures can also be retained using a highlight mask (Jaffe et al, 76-77).

Masking can help produce a correct black printer. In normal color separation techniques, the black printer produces some black in pure colors. The masking will reduce the amount of black in these colors (Jaffe et al, 76).

The photographic masks can be made two ways. The first way is on the process camera back. They are made from either reflective or transparent copy, processed, and replaced in the camera back. The second way is in a contact frame. Contact masks are made from transparency originals or from the separation negatives (Jaffe et al, 77-78).

### **Undercolor Removal**

A special type of masking, called undercolor removal, is sometimes used in



printing four color work (Jaffe et al, 76). Undercolor removal involves removing neutral grays caused by equal parts of cyan, magenta, and yellow and replacing these grays with the black printer. In theory, anywhere all three subtractive primaries are overprinted, they are to be reduced in equal amounts until the color with the smallest amount of coverage is eliminated completely. The darkening of the color is then achieved by the black printer. This full undercolor removal tends to cause registration problems, so a partial removal is usually preferred (Hunt, 588).

Undercolor removal offers many advantages. Since most darkening is due to the black printer, better consistency in the gray scale can be maintained. A sharper rendering of fine detail in the shadow areas is apparent. Less ink is used, one color as opposed to three, which allows for savings in ink costs and faster ink drying times (Hunt, Plate 35, pages 544-545).

Although theoretically undercolor removal can be accomplished photographically, it is almost always done electronically. It is calculated mathematically from the actual data in the original scanned image and subtracted proportionally. This allows much more control than is possible with photographic processes (Adams, Faux, and Rieber, 261).

### **Color Proofing**

Once the separations are made, proofing is generally the next step. This allows the image to be viewed for errors in separation before it gets printed. Analog proofs are those made directly from the separation negatives. Overlay proofs and laminate or single-piece proofs are the two types of analog proofs (Esler, 40).

Overlay proofs are separate transparent proofs made for each color. They are laid over each other in register to produce a color proof. Overlay proofs allow for the

dot patterns of each color to be inspected individually by turning back the colored sheets. Another advantage is that overlay proofs can be placed on top of the printing stock that is to be used. Some overlay proofing systems include: Fuji's Color Check, 3M's Color Key, Kodak's Accord, Hoechst's Naps and Paps, and Du Pont's Chromacheck and Chromatone (Esler, 43-44).

With the laminate proofing systems, each film has an embedded process color. After the film is exposed, the non-image area is washed or pulled away. The four films are then laminated in register to produce the color proof. Single-piece proofs show dot gain and color trapping on simulated or actual stock. Another advantage is that they are consistent from proof to proof despite the conditions under which the proof was made. The single-piece proofs are able to be folded into the shape of the finished product. Some laminate proofing systems include: Du Pont's Chromalin, 3M's Matchprint II and Matchprint III, Kodak's Contact, Polychrome's Chromeproof, Fuji's Color-Art, Hoechst's Pressmatch, and Agfa's Agfaproof (Esler, 40-44).

The alternative to analog proofing systems is direct digital color proofing. These proofs are not made from separation negatives, but are direct outputs from electronic publishing systems. There are two options of direct digital color proofing: a continuous-tone or no-dot output and a system that outputs a proof with halftone dots (Wilken, 42).

The continuous tone output systems use high-end dye sublimation, ink jet, and non-impact laser technologies. An advantage to no-dot systems is that full-color information can be proofed without screening the original image (Wilken, 43).

The direct digital proofing systems with halftone outputs were first introduced in 1990. Three main suppliers of this type of system are 3M, Screen (USA), and Eastman Kodak. 3M uses a patented electrophotographic process called Digital

Matchprint. Screen (USA)'s system uses a laser exposure unit (Wilken, 42-43).

Kodak's Approval system uses a proprietary dry-process laser technology. According to Eastman Kodak Company, digital information is raster image processed and sent to the Approval digital color imager. The imager wraps a receiver medium around a drum along with up to five color donors, allowing for a specialty color. The laser transfers all of the colors to the receiver. The receiver is then placed in contact with stock and laminated. The main advantage to these systems is the ability to produce analog-type proofs digitally. The Approval system, as an example, lets you control settings for screen angle, screen rulings, dot shape, and dot gain in order to simulate the printed page (Imaging, 4, 7).

### **Electronic Prepress**

Electronic composition systems provide five basic functions: input, information storage, composition, editing, and output. Input devices include keyboards and image scanners. Menu-driven systems use a mouse or a pen for input as well (Adams, Faux, and Rieber, 104-112).

Scanners are used to digitally record images. The picture images are converted into electrical signals one point at a time. Scanners are capable of producing continuous tone or screened separations that are totally color corrected (Hunt, 578).

One type of scanner used in graphic arts is the drum scanner. A drum scanner has a transparent cylinder, or drum, that rotates at a rapid rate. A color transparency is wrapped around the drum and a light beam is passed through the transparency as the drum rotates. The light moves longitudinally along the transparency until the entire surface is scanned. The light that passes through the transparency is recorded by photocells and converted to electronic signals by a computer. A disad

vantage of drum scanners is that images must be transparencies or copied on to color transparency film before they can be scanned (Hunt, 582-583).

Another type of scanner is a flat-bed scanner. The advantage of this type of scanner is that it can produce fully corrected separations from color transparencies or flat copy (Hunt, 583). Flat-bed scanners have an internal light source that reflects light off of the copy. The photocells measure this reflected light instead of a transmitted light. Transparencies have to have a white background, usually part of the scanner, so that the light will be reflected back to the photocells.

A third type of scanner is designed specifically for scanning 35 mm transparency and negative film. These scanners are called film or negative scanners. The film is placed between the light source and the photocells. The light source illuminates the entire film in one pulse. The image is recorded all at once. However, it has to make a separate scan for red, blue, and green, so the image is scanned three times instead of just once. Some companies that manufacture 35mm film scanners include: Eastman Kodak, Nikon, Leaf Systems, Eikonix, and Howtek (Turning Photographs, 4).

Information can be stored on magnetic tapes. These are mostly used to back up information from other storage devices. Magnetic disks are commonly used to store data. The two main types of magnetic disks are floppy disks and hard disks. The floppy disks are flexible plastic disks that are small and portable. The amount of data that these disks can hold is quite limited. A hard disk contains several rigid disks that are stacked on top of one another. A hard disk can hold much more information than a floppy disk and can retrieve information at a much faster rate (Adams, Faux, and Rieber, 109-110). Removable hard disks are hard disks that are contained in cartridges. The advantage of a removable hard disk is that when it stores all of the information it can hold, another cartridge can be purchased for far

less than a new fixed hard disk. The removable disks are also portable. Optical disk drives are also available. A magneto optical disc can hold 450 to 600 megabytes of data. They are removable and portable as well (Turning Photographs, 5-7).

Editing and composition are done through the use of software programs. There are a wide variety of software programs. Word processing software allows text editing and composition. Microsoft Word and Works, ClarisWorks and MacWrite, and WordPerfect are some common word processing programs (Turning Photographs, 4-5).

Other editing and composition software categories include: image editing software and design software. Color separation software is one type of image editing software. Aldus PrePrint, Adobe Separator, and Pre-Press Technologies SpectreSeps are some color separation programs that are available. Image editing software also includes retouching programs for scanned images such as Adobe Photoshop, Aldus Digital Darkroom, Avalon PhotoMac, Letraset ColorStudio, and SuperMac PixelPaint Professional (Turning Photographs, 4-5).

Design software allows drawing, layout, and layout management to be accomplished. Among the drawing programs are Aldus Freehand and SuperPaint, Adobe Illustrator, Claris MacDraw and MacPaint, and Cricket Draw from Computer Associates. Quark's QuarkXPress and Aldus' PageMaker are two layout programs. Layout management programs that organize multiple page layouts include PressWise by Aldus and Page Director by Managing Editor (Turning Photographs, 4-5).

Monitors, digital proofing devices, PostScript raster image processors, and imagesetters are all output devices. Digital proofing devices are also referred to as printers. These include: black and white laser printers, thermal-wax transfer printers, dye sublimation printers, inkjet printers, and color laser printers (Turning

Photographs, 5-7). Imagesetters produce high quality, laser generated images that can be output onto photosensitive paper, film, or plate material. PostScript raster image processors convert the data that is outputted into a format that the imagesetter can interpret.

### **Color Control**

Density is the darkness of a material. The density of a material is measured by the amount of light that it absorbs. The more light that a material absorbs, the higher its density. Density of an image or a color is measured by a photoelectric instrument called a densitometer (Color Communication, 18).

A transmission densitometer is used to measure the density of graphic arts films. A transmission densitometer transmits a beam of light from an internal light source through the film. The light that passes through the film is measured. This light is the amount of light that was not absorbed by the film. This amount of light is subtracted from the total amount of light by the densitometer to calculate the density of the film (Densitometry, 8).

Transmission densitometers calculate dot area of halftone films as well as density. These two types of measurements are used to inspect films, check the accuracy of duplicating films, and calibrate imagesetters and scanners. Measuring a film's clear area tests to see if the film was fogged. The dark area's measurement checks for proper exposure and processing. Measurement of a dot area assures that film tints and screens are accurate (Densitometry, 1,8).

While a transmission densitometer measures transmitted light, reflected light is measured by a reflection densitometer. Color reflection densitometers utilize filters to make separate color readings. These useful control tools can calculate

density, trap, dot gain, print contrast, hue error, and grayness on printed substrates. These can be easily measured on a color control bar that is printed on each page (Densitometry, 7-9).

The press operator monitors the reflection density of each color of ink to make sure that the right amount of ink is being printed. Too much or too little ink will cause color shifts, especially in two color overprints. Trapping is the extent that one layer of ink accepts the next layer of ink compared to the paper. Poor trapping also causes color shifts in reds, greens, and blues, the two color overprints (Densitometry, 2,4).

Dot gain is the amount that a printed dot swells on a printed stock compared to the original dot size in the film. The detail in a halftone image comes from the dot size. When dots grow on the printed product detail is lost. If there is dot gain in one or two colors, color shifts and tints will occur. Dot gain is usually measured three times for each color on a color bar: 25% dot area for highlights, 50% dot area for midtones, and 75% dot area for shadows. Print contrast compares the 75% dot area to the solid area for each color to indicate how well the shadow detail is maintained (Densitometry, 3,5).

Hue error and grayness measure the consistency of inks, colors of proofs, and inks printed on paper. Hue error tells the amount of impurity in an ink. Grayness is the amount of gray in a color. Grayness and hue error should be kept as consistent as possible so accurate colors can be reproduced (Densitometry, 6).

Scanning densitometers are special reflection densitometers that automatically scan color bars. These instruments automatically enter data to a computer that analyses it. This speeds up the measurement and allows the press operator to maintain tighter color control (Densitometry, 8).

## **CIEL\*a\*b\* Color Measurement System**

Everyone perceives and interprets colors differently. In graphic arts, color needs to be communicated often and accurately. Therefore, a system of color standards is necessary. The standards must be able to be measured by an instrument that can differentiate a color from all other colors and assign a numeric value to that color (Color Communication, 4).

The Commission Internationale de l'Eclairage (CIE), translated as the International Commission on Illumination, is responsible for international recommendations of color measurement standards. One of the most current and widely used CIE color measurement models is the CIEL\*a\*b\*, or CIELAB. This model is based on the theory that color can not be both blue and yellow at the same time, nor can it be both red and green at the same time (Color Communication, 10).

The purpose of CIELAB is to represent every visible color with a numeric value. In this model, all of the colors together are expressed as a sphere. The center axis is the lightness factor. The  $L^*$  in CIEL\*a\*b\* stands for lightness and is measured upon this axis. The bottom point of the sphere is  $L^*=0$ , or black because there is no lightness. Likewise, the top point of the sphere is  $L^*=100$ , or white because there is 100% illumination (Color Communication, 10-11).

Once  $L^*$  has been defined, color no longer has to be thought of as a sphere. The color is now a plane of that sphere at point  $L^*$  on the axis. The outer most circle of this plane defines the hue. The  $a^*$  in CIEL\*a\*b\* is the line that runs between the green hue and the red hue, which are opposite one another on the circle. Likewise,  $b^*$  is the line that runs between the blue and yellow hues. Line  $a^*$  and line  $b^*$  intersect at a  $90^\circ$  angle at point  $L^*$  on the plane. The intersection of these points is assigned the number  $L^*,0,0$ . This is because that point is absent from any color and is



only a shade of gray. A pure CIEL\*a\*b\* hue, located on the outer circle, is given the value of  $\pm 60$ . Red and yellow are +60 units from the center point ( $L^*$ ). Green and blue are -60 units from the center point ( $L^*$ ) [see Appendix]. With this information, all of the colors can be graphed using  $L^*$  as a starting point and  $a^*$  and  $b^*$  as an X and Y axis, respectively (Color Communication, 10-11).

For example,  $L^*=50$   $a^*=30$   $b^*=-25$ . In this case, the axis point of this plane would be half black and half white ( $L^*=50$ ). The color would be 30 units toward red ( $a^*=30$ ) and 25 units toward blue ( $b^*=-25$ ). The resulting color would be a purple. This system allows for colors to be mathematically measured, expressed, and matched.

Colorimeters are instruments that measure all colors. Unlike densitometers that are designed to measure process colors, colorimeters take tristimulus readings of red, blue, and green and specifies colors according to CIEL\*a\*b\*, or a similar color measurement model (Color Communication, 5).

Another instrument called a spectrophotometer measures many points along the spectrum. These points make up a curve called a spectrophotometric curve. This curve shows the amounts of the colors of light that were present and absent from the material that was measured (Color Communication, 5).

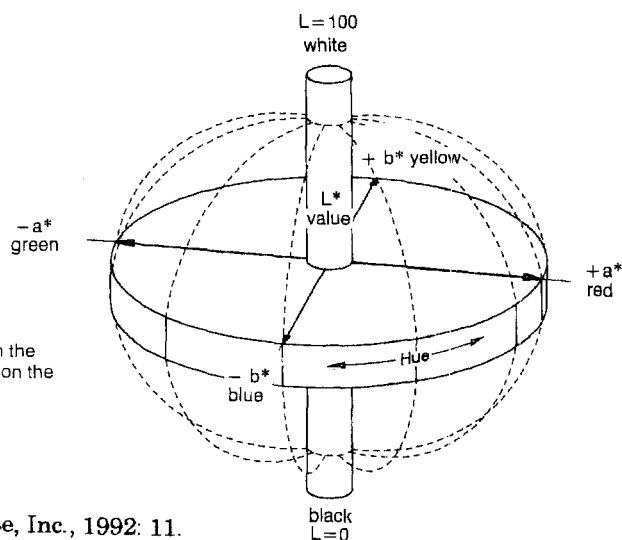
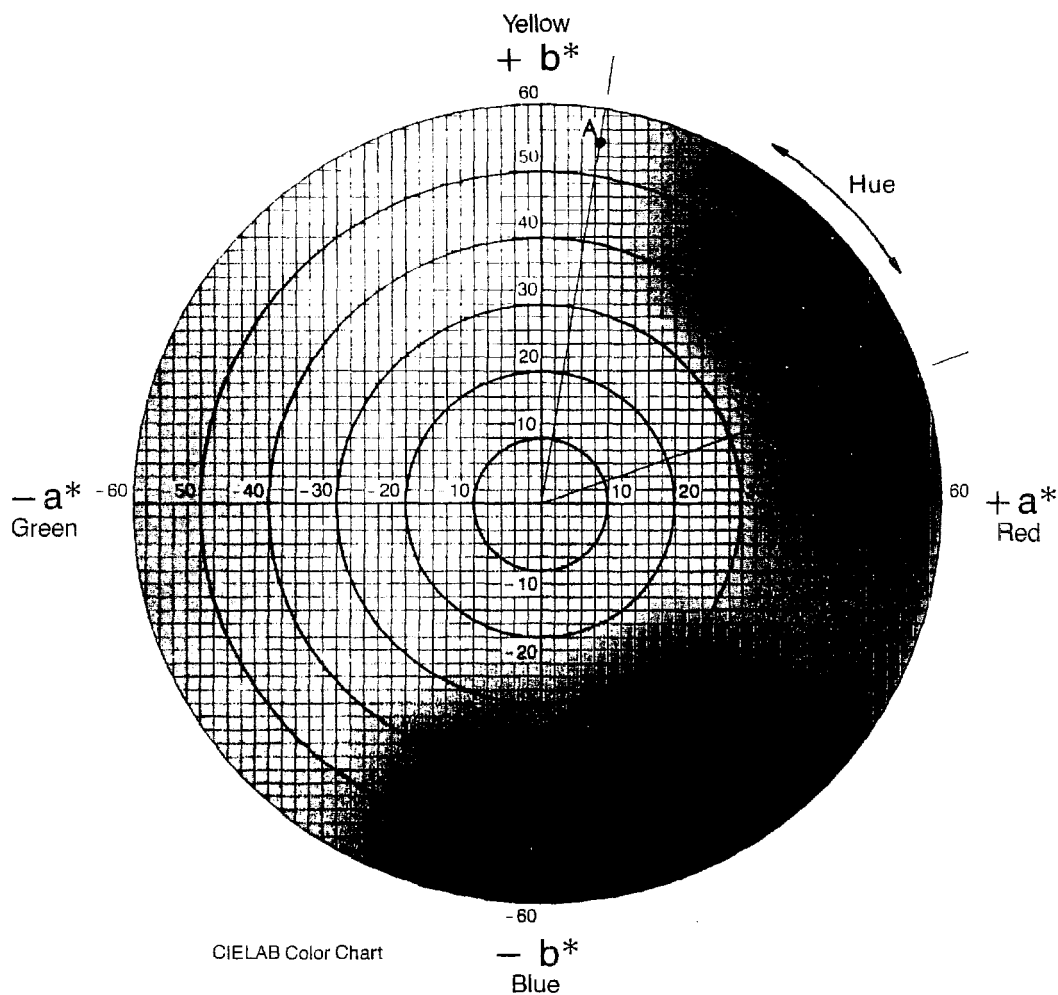
The most recent color measurement device is called a spectrodensitometer. This is a spectrally-based densitometer. A spectrodensitometer combines the functions of a densitometer, colorimeter, and a spectrophotometer (Densitometry, 7-8).

## Conclusion

Color theory is a complex and interesting topic. Applying that theory to the graphic arts is challenging and exciting. Color technologies in the printing industry

are advancing at a steady rate. For people involved with this industry, color theory must be applied continuously. The procedures for reproducing color may change because of new technology, but the theories behind these procedures remain the same. A good fundamental knowledge of graphic arts color theory is a valuable asset to possess in the printing industry.

# Appendix



The  $L^*$  value is represented on the center axis. The  $a^*$  and  $b^*$  axes appear on the horizontal plane.

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